PHN 17 817
US 1/3

jc531 U.S. PTO
09/741670
12/19/00

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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

99204401.6

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

Anmeldung Nr
Application no 99204401.6
Demande n°

Anmeldetag:
Date of filing: 20/12/99
Date de dépôt:

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Bezeichnung der Erfindung
Title of the invention
Titre de l'invention

An arrangement for receiving a digital signal from a transmission medium

In Anspruch genommene Prioriat(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

Staat / State / Pays	Tag / Date / Date	Aktenzeichen: / File no. / Numéro de dépôt:

Internationale Patentklassifikation
International Patent classification
Classification internationale des brevets

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Am Anmeldetag benannte Vertragstaaten
Contracting states designated at date of filing AT/BE/CH/CY/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE
Etats contractants designes lors du depôt

Bemerkungen
Remarks
Remarques

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An arrangement for receiving a digital signal from a transmission medium.

The invention relates to an arrangement for receiving a digital signal from a transmission medium. Said arrangement comprises:

- input means for receiving a signal from the transmission medium,
- asynchronous sampling means for sampling an analog signal so as to obtain a first signal having asynchronous samples,
- variable equalizer means having an input coupled to an output of the input means, a control signal input for receiving a control signal and an output for supplying an equalized signal,
- equalizer control signal generator means, having an input and an output for supplying an equalizer control signal, which output is coupled to the control signal input of the equalizer means,
- signal detector means, having an input coupled to the output of the variable equalizer means and an output for supplying the digital signal, the signal detector means being adapted to detect the digital signal from the equalized signal,
- an output terminal coupled to the output of the signal detector means for supplying the digital signal.

An arrangement defined above is known from EP 0 387 813 A2. Said document describes arrangement comprising a variable equalizer. The arrangement receives a signal from the transmission medium. An analog-to-digital converter converts the received signal into a first digital signal having asynchronous samples. The variable equalizer equalizes the first digital signal so as to obtain an equalized signal. A PLL circuit obtains from the equalized signal synchronous samples of the digital signal. An equalizer control signal generator unit processes the synchronous samples so as to obtain an equalizer control signal for controlling the variable equalizer. The equalizer control signal generator unit comprises a detection unit. The detection unit detects the error rate of the digital signal. The error rate strongly depends on the proper functioning of the PLL circuit and bit detection unit. The equalizer control signal unit generates in response to the error rate the equalizer control signal.

It is an object of the invention to provide an arrangement for receiving a digital signal with which it is possible to control the variable equalizer faster and not dependent of the functioning of a PLL circuit.

The arrangement in accordance with the invention is characterized in that, the input of the equalizer control signal generator means is adapted for receiving a second signal having asynchronous samples, the equalizer control signal generator means comprises detection means for detecting the moment on which the second signal crosses a predetermined signal value so as to obtain a detection signal and means for deriving in response to said detection signal the equalizer control signal from at least one asynchronous sample value of the second signal on each side of the moment the second signal crosses said predetermined signal value, said equalizer control signal being derived from said at least two samples by a derivation equivalent to arithmetically combining said at least two asynchronous sample values.

The invention is based on the following recognition. In order to correct variations in the received signal a robust error signal must be derived from the incoming signal. The received signal, representing sequence of bits, can be obtained from a transmission medium such as an magnetic record carrier, for example a magnetic tape, an optical record carrier, for example an optical disk or a transmission channel, for example a broadcasted signal. If the signal is obtained from a magnetic tape, the signal can be distorted by head-to tape distance resulting in a variation in attenuation of the high frequencies in the received signal. Further the roughness of the tape or wear of the reading head can attenuate the high frequencies in the received signal. If the signal is received from an optical disk, the signal can be distorted by tilt of the disk, resulting in a phase change of the high frequencies. It has been found that the result of arithmetical combinations of one asynchronous sample value on each side of a zero crossing of the binary signal has a relationship with said mentioned distortions. Said result is used to generate the control signal for controlling the variable equalizer.

In an embodiment of the arrangement, the arrangement is characterized in that an input of the asynchronous sampling means is coupled to the output of the input means and an output of the asynchronous sampling means is coupled to the input of the variable equalizer means and the input of the equalizer control signal generator means is coupled to the output of the variable equalizer means for receiving said second signal having asynchronous samples. In this embodiment the variable equalizer is in the form of a digital variable equalizer. Preferably, the variable equalizer is in the form of a finite impulse response filter. A FIR filter

having a DC gain of 1 and adapted to compensate the attenuation of high frequencies could be in the form of a 3-tap FIR filter having a transfer function $H(z) = C_0 + 2C_1 z^{-1} + C_0 z^{-2}$ and whereby $C_0 = 1/2 - C_1$. A FIR filter to compensate the phase change of high frequencies could be in the form of a 3-tap FIR filter having a transfer function $H(z) = \Delta + z^{-1} - \Delta z^{-2}$. To compensate both the attenuation and the phase change of high frequencies a 3-tap FIR filter having a transfer function $H(z) = (C_0 + \Delta) + 2C_1 z^{-1} + (C_0 - \Delta) z^{-2}$ and whereby $C_0 = 1/2 - C_1$ could be used.

In an other embodiment of the arrangement, the arrangement is characterized in that , an input of the asynchronous sampling means is coupled to the output of the variable equalizer means and the input of the equalizer control signal generator means is coupled to an output of the asynchronous sampling means for receiving said second signal having asynchronous samples. In this embodiment the variable equalizer means is in the form of an analog filter.

In an further embodiment of the arrangement, the arrangement is characterized in that, said arithmetically combining means comprises the formula: $S(t) = c \times | X(t) - X(t-1) |$ whereby X(t) is a sample of the second signal directly following the moment on which the second signal crosses a predetermined signal value, X(t-1) is a sample of the second signal directly preceding said moment, c is a constant and S(t) equals an intermediate signal for deriving said equalizer control signal. In the received signal high frequencies can be attenuated due to for example head-to-tape distance or high frequency losses due to the transmission medium. Said formula calculates the slope of the signal around a zero crossing. Said slope has a relationship with the amplitude of high frequencies in the signal. It appears that the amplitude has an almost linear relationship with the head-to-tape distance and therefore easy to use as an error signal in a control loop.

In an other embodiment of the arrangement, the arrangement is characterized in that, said arithmetically combining means comprises the formula: $S(t) = c \times | X(t) + X(t-1) |$ whereby X(t) is a sample of the second signal directly following said moment, X(t-1) is a sample of the second signal directly preceding said moment, c is a constant and S(t) equals an intermediate signal for deriving said equalizer control signal. The thus obtained intermediate signal has a relation with the difference in delay caused by the transmission path between low frequency signals and high frequency signals in the operating frequency range of the transmission path. Said intermediate signal is used to control the variable equalizer means so as to correct for said difference in delay. A difference in delay can also be caused by for example tangential tilt of an optical record carrier.

To reduce fast variations of the intermediate signal the intermediate signal might be averaged. Further the equalizer control signal generator means may comprises a look up table so as to obtain the equalizer control signal. In stead of a processor to perform the arithmetical combination of the at least two asynchronous sample values, a look up table may be used. The complexity of the arithmetical combination determines which solution will be preferred. For example a non-linear combination with a limited input range will be implemented cost effective with a look up table.

These and other aspects of the invention will be apparent from and elucidated with respect to the embodiment described hereafter in the figure description in which

Figure 1 shows a first embodiment of an arrangement in accordance with the invention,

Figure 2 shows an input signal and differences around zero crossings,

Figure 3 shows the slope signal versus signal loss at $F_{Nyquist}$,

Figure 4 shows a coefficient update loop,

Figure 5 shows a second embodiment of an arrangement in accordance with the invention.

Figure 6 shows a third embodiment of an arrangement in accordance with the invention.

Figure 1 shows a first embodiment of an arrangement in accordance with the invention. The arrangement is adapted for receiving a digital signal from a transmission medium. Signals received from the transmission medium by means of the receiving unit 2 are supplied to an AD converter 4. The receiving unit 2 may comprise receiving means for receiving a transmitted signal or a reading unit for reading a signal from a magnetic or optical record carrier, which record carrier may be in the form of a disk or tape. The AD converter 4 samples the read analog signal so as to obtain a first signal having asynchronous samples. The first signal is supplied to input 8 of a variable equalizer unit 6. The variable equalizer unit 6 is adapted to equalize the transmission characteristic of the transmission path including the transmission medium up to the input 8 of the variable equalizer unit 6 in response to an equalizer control signal supplied to a control input 10 of the variable equalizer unit 6 so as to obtain an equalized signal. The equalized signal is supplied to a bit detection unit 12. The bit

detection unit comprising a PLL and a bit detector, is adapted to detect bits in the equalized signal so as to obtain the digital signal. The digital signal is supplied to an output terminal 14.

The arrangement further comprises a unit 16 for generating a first control signal in dependence of the equalized signal. Optionally, the first control signal is processed by a unit 18 for averaging the first control signal prior to supplying the first control signal to an input 22 of an equalizer control signal generation unit 20. The equalizer control signal generation unit is adapted for generating an equalizer control signal in response to the signal supplied to its input 22, and for supplying the equalizer control signal to the control input 10 of the variable equalizer means 6. The equalizer control signal generation unit 20 derives in response to the signal supplied to its input 10. The first control signal or the averaged first control signal may have a relation with the high frequency losses in the magnitude transmission characteristic of the transmission path. For example, the head-to-tape distance causes said losses during reproduction. The first control signal may also have a relation with differences in delay caused by the transmission in said transmission path between low frequency signals and high frequency signals in the operating frequency of the transmission path. Differences in delay can occur when reading a signal from an optical record carrier such as a CD, for example due to that the whole optical record carrier has tilt with respect to the laser beam. Due to deformation of the optical record carrier in the form of a disk, the difference in delay may vary with every rotation of the disk. The difference in delay even varies with the radius of a track on said record carrier.

The arrangement described above functions as follows. The digital information signal is received by the receiving unit 2 and sampled by the AD converter so as to obtain a first signal having asynchronous samples. Figure 2 shows an example of the first signal in the form of a random 8 to 9 encoded read back signal from tape. The first signal in figure 2 is Nyquist-I equalized. The Nyquist-I equalization may be done in a pre-amplifier unit, not shown, prior or after the AD converter. The first signal is equalized in the variable equalizer so as to obtain the equalized signal.

The variable equalizer 6 is adapted to equalize the transmission characteristic of the transmission channel including the recording channel up to the input 8 of the variable equalizer 6. The variable equalizer is preferable a 3 tap Finite Impulse Response Filter. However any other suitable filter type may be used. To correct high frequency losses the FIR-filter has preferably the transfer function: $H(z) = C_0 + 2C_1 z^{-1} + C_0 z^{-2}$, whereby $C_0 = 1/2 - C_1$. To correct differences in delay the FIR-filter has preferably the transfer function $H(z) = \Delta + z^{-1} - \Delta z^{-2}$. To correct both high frequency losses as well as differences in delay the

FIR-filter has preferably the transfer function $H(z) = (C_0 + \Delta) + 2C_1 z^{-1} + (C_0 - \Delta) z^{-2}$, whereby $C_0 = 1/2 - C_1$.

The equalized signal is supplied to input 24 of unit 16. Unit 16 comprises signal detector means for detecting the moment on which the signal received at input 24 crosses a predetermined signal value so as to obtain a detection signal. Unit 16 further comprises means for deriving in response to said detection signal an error signal from at least one sample value of the signal received at input 24 on each side of the moment said signal crosses said predetermined signal value. The predetermined signal value may be fixed for example the zero value or the DC signal value. But if the signal has a varying mean signal value the predetermined signal values may have a relation with said varying mean signal value. Figure 2 shows an error signal obtained by calculating the slope around zero crosses by subtracting a sample value directly after a zero crossing and a sample value directly preceding said zero crossing. Since the error signal is obtained from a nominal equalized signal, the error signal has an near to constant value.

It has been found that the head-to-tape distance loss has a relation with the slope of the signal around zero crossing. Figure 3 shows the slope of the signal around zero crossings versus the amplitude at $F_{Nyquist}$. The head-to-tape distance loss may be expressed as the loss of amplitude at $F_{Nyquist}$. There the slope signal, see error signal in figure 2, also has near to constant value for a nominal equalized signal, the slope signal can be used as a control signal. A first control signal having a relation with the head-to-tape distance preferably the first sample values on each side of the moment the signal crosses the predetermined value may be obtained by the following arithmetical combination: $S(t) = c \times | X(t) - X(t-1) |$, whereby S(t) is the first control signal, X(t) is a sample of the signal directly following said moment X(t-1) is a sample of said signal directly preceding said moment and c is a constant. A first control signal having a relation with a relation with the difference in delay preferably the first sample values on each side of the moment the signal crosses the predetermined value may be obtained by the following arithmetical combination: $S(t) = c \times | X(t) + X(t-1) |$, whereby S(t) is the first control signal, X(t) is a sample of the signal directly following said moment X(t-1) is a sample of said signal directly preceding said moment and c is a constant. The thus obtained first control signals are used in a control loop to correct for the head-tape distance variations and/or the differences in delay.

Prior to supplying the first control signal to the equalizer control signal generator unit 20, the first control signal may be processed by unit 18 so as to obtain a less varying control signal so as to obtain a less noisy control loop. The unit 18 may be adapted to

generate an averaged first control signal by averaging the values of for example the last N generated first control signal values. However, any other suitable methods to generate a less varying first control signal might be used.

The equalizer control signal unit 20 generates from the first control signal, or it averaged representation, the equalizer control signal. The equalizer control signal may comprise the values for filter coefficients of the FIR filter in the variable equalizer. However, depending on the complexity of the variable equalizer, the variable equalizer may be adapted to generate the coefficients of the FIR filter internally from the equalizer control signal. In this case the equalizer control signal has a relationship with the coefficients to be used in the variable equalizer. As said before, the head-to-tape distance variations can approximately compensated with a simple 3-tap FIR filter having a transfer function $H(z) = C_0 + 2C_1 z^{-1} + C_0 z^{-2}$, whereby $C_0 = ½ - C_1$. The middle tap $2C_1$ is calculated from the first control signal such that the boost of the filter matches the measured loss. The two outer taps having the same value are calculated such that the DC-gain of the filter remains constant, for example the DC-gain equals to 32. The coefficient C_1 is preferably calculated with the following formula:

$$c1' = c1 + \alpha.(c1 - 8).(\tfrac{reference}{S(t)} - 1)$$

Whereby S(t)is the value of a sample of the first control signal, the parameter reference is a reference value having a relationship with the required nominal slope around the zero crossings, c1 is the current value of the parameter C_1 in the transfer function and c1' is the next value of the parameter C_1 in the transfer function. The parameter reference controls the nominal boost of the FIR filter and the measured slope around the zero crossing in the equalized control signal. With the gain variable α the bandwidth of the loop is controlled. Further, α controls the amount of averaging one by the loop. The coefficient C_0 can be obtained with the formula: $C_0 = 16 - C_1$.

The calculation of coefficient c1 is preferably done with a look up table (LUT) because of the non-linear form of the formula. The first control signal, the parameter reference and the current value of C_1 are in this case input signals for the look up table. The output signal of the look up table is the new value of the middle tap's coefficient C_1.

Preferably, two restrictions are made in the implementation of the control loop, namely a minimal boost (0dB) and a maximal boost (10dB) of the FIR filter. This could be done because outside these regions the FIR will probably not gain performance any more.

With C_0 = 0 and C_1 = 16 the FIR filter has a boost of 0dB. With C_0 = -16 and C_1 = 32 the FIR filter has a boost of 10dB at the sample frequency of the FIR filter.

Figure 4 shows an embodiment of an update loop of the coefficients. It is a proportional loop where some averaging is achieved by choosing a proper value of α. Input terminal 40 receives the equalized signal. Unit 42, performing the function of unit 16 in figure 1, processes the equalized signal so as to obtain the first control signal. Unit 44 subtract a reference signal from the first control signal so as to obtain an error signal. Unit 46 processes the error signal and the current coefficient C_1 so as to obtain a normalized adjustment signal. Unit 48 is adapted to multiply said normalized adjustment signal with the parameter α so as to obtain an adjustment signal. The signal combination unit 50 is adapted to add the adjustment signal to the signal being the current coefficient C_1 so as to obtain the next value of coefficient C_1. The thus obtained next value of C_1 is equal to c1' in the before-mentioned formula. Unit 52 is adapted to limit the next value of coefficient C_1 to the coefficient value range for the minimal and maximal boost so as to obtain the next value of coefficient C_1. The next value of coefficient C_1 is supplied to the variable equalizer of delaying in delay unit 56. The units 44, 46, 48 and 50 perform the before-mentioned formula and may be realized in a look-up table 54 so as to obtain the next value of coefficient C_1. It should be noted that the function of unit 52 can be integrated in the look-up table 54.

Figure 5 shows a second embodiment of the arrangement in accordance with the invention. This embodiment is a slightly different version of the arrangement of figure 1, in that the variable equalizer 6' in the form of an analog filter is adapted to filter the received signal so as to obtain an analog equalized signal. Further, the analog equalized signal is supplied to a bit detection unit 12' adapted to detect a sequence of bits in the analog equalized signal. The analog equalized signal is further supplied to an analog to digital converter 4'. Said AD converter 4' is adapted to obtain the first signal having asynchronous samples. The first signal is successively processed by unit 16, unit 18 and unit 20' so as to obtain a variable equalizer control signal for control the transfer function of the analog variable equalizer.

Figure 6 shows a third embodiment of the arrangement in accordance with the invention. The units having reference signs equal to reference signs of units in figure 1 have been described in the description of figure 1. In this embodiment the variable equalizer is controlled with a feed-forward control loop. An equalizer control signal generator unit 20" is in this embodiment adapted to generate the equalizer control signal in response to the first control signal, or averaged first control signal supplied by unit 16 or unit 18 respectively.

With the third embodiment the variable equalizer can be controlled faster as with the embodiments having the feed back loop for controlling the variable equalizer.

Whilst the invention is described with reference to preferred embodiments thereof, it is to be understood that these are not limitative examples. Thus various modifications may become apparent to those skilled in the art, without departing from the scope of the invention, as defined by the claims. As an example, the input of the bit detector 12' in the second embodiment may be coupled to the output of the AD converter 4'. In this case the bit detector 12' may be the same bit detector as in the first embodiment in figure 1.

The word 'comprising' does not exclude the presence of other elements or steps than those listed in a claim. Any reference signs do not limit the scope of the claims. The invention may be implemented by means of both hardware and software. Several "means may be represented by the same item of hardware. Further the invention lies in each and every novel feature or combination of features.

CLAIMS:

1. An arrangement for receiving a digital signal from a transmission medium, the arrangement comprising:
- input means for receiving a signal from the transmission medium,
- asynchronous sampling means for sampling an analog signal so as to obtain a first signal having asynchronous samples,
- variable equalizer means having an input coupled to the input means, a control signal input for receiving a control signal and an output for supplying an equalized signal,
- equalizer control signal generator means, having an input and an output for supplying an equalizer control signal, which output is coupled to the control signal input of the equalizer means,
- signal detector means, having an input coupled to the output of the variable equalizer means and an output for supplying the digital signal, the signal detector means being adapted to detect the digital signal from the equalized signal,
- an output terminal coupled to the output of the signal detector means for supplying the digital signal,
characterized in that, the input of the equalizer control signal generator means is adapted for receiving a second signal having asynchronous samples, the equalizer control signal generator means comprises detection means for detecting the moment on which the second signal crosses a predetermined signal value so as to obtain a detection signal and means for deriving in response to said detection signal the equalizer control signal from at least one asynchronous sample value of the second signal on each side of the moment the second signal crosses said predetermined signal value, said equalizer control signal being derived from said at least two samples by a derivation equivalent to arithmetically combining said at least two asynchronous sample values.

2. Arrangement as claimed in claim 1, characterized in that, an input of the asynchronous sampling means is coupled to the input means and an output of the asynchronous sampling means is coupled to the input of the variable equalizer means and the

input of the equalizer control signal generator means is coupled to the output of the variable equalizer means for receiving said second signal having asynchronous samples.

3. Arrangement as claimed in claim 1, characterized in that, an input of the asynchronous sampling means is coupled to the input means and an output of the asynchronous sampling means is coupled to the input of the variable equalizer means and the input of the equalizer control signal generator means for receiving said second signal having asynchronous samples.

4. Arrangement as claimed in claim 2 and 3, characterized in that, the variable equalizer means comprises a FIR filter.

5. Arrangement as claimed in claim 4, characterized in that, the FIR filter is a 3-tap FIR filter having a transfer function: whereby preferably $H(z) = C_0 + 2C_1 z^{-1} + C_0 z^{-2}$ and C_0 and C_1 being variables values for which holds $C0 = 1/2 - C_1$, having a relationship with the equalizer control signal.

6. Arrangement as claimed in claim 4, characterized in that, the FIR filter is a 3-tap FIR filter having a transfer function: whereby preferably $H(z) = \Delta + z^{-1} - \Delta z^{-2}$, Δ being a variable having a relationship with the equalizer control signal.

7. Arrangement as claimed in claim 4, characterized in that, the FIR filter is a 3-tap FIR filter having a transfer function: whereby preferably $H(z) = (C_0 + \Delta) + 2C_1 z^{-1} + (C_0 - \Delta) z^{-2}$ and C_0, C_1 and Δ being variables having a relationship with the equalizer control signal for which holds $C_0 = ½ - C_1$.

8. Arrangement as claimed in claim 1, characterized in that, an input of the asynchronous sampling means is coupled to the output of the variable equalizer means and the input of the equalizer control signal generator means is coupled to an output of the asynchronous sampling means for receiving said second signal having asynchronous samples.

9. Arrangement as claimed in any of the preceding claims, characterized in that, said arithmetically combining means comprises the formula:
$S(t) = c \times | X(t) - X(t-1) |$ whereby $X(t)$ is a sample of the second signal directly following said

moment, X(t-1) is a sample of the second signal directly preceding said moment, c is a constant and S(t) equals an intermediate signal for deriving said equalizer control signal.

10. Arrangement as claimed in any of claims 1 to 7, characterized in that, said arithmetically combining means comprises the formula:
$S(t) = c \times | X(t) + X(t-1) |$ whereby X(t) is a sample of the second signal directly following said moment, X(t-1) is a sample of the second signal directly preceding said moment, c is a constant and S(t) equals an intermediate signal for deriving said equalizer control signal.

11. Arrangement as claimed in any of claims 9 or 10, characterized in that, the equalizer control signal generator means comprise means for averaging the intermediate signal so as to obtain an averaged signal, whereby the equalizer control signal is generated in response to said average signal.

12. Arrangement as claimed in any of the preceding claims, characterized in that the equalizer control signal generator means comprises a look up table so as to obtain the equalizer control signal in response to the first control signal.

ABSTRACT:

An arrangement is disclosed for receiving a digital signal from a transmission medium. The arrangement comprises a variable equalizer (6) for equalizing a received signal so as to obtain an equalized signal and a bit-detector (12) for detecting a sequence of bits from the equalized signal. Further the arrangement comprises an asynchronous sampling unit (4) for sampling a received analog signal so as to obtain a first signal having asynchronous samples. From the values of at least one sample of a signal having asynchronous samples, at each side of a zero crossing in said signal, a control signal is generated to control the variable equalizer (16, 18, 20).

Fig. 1

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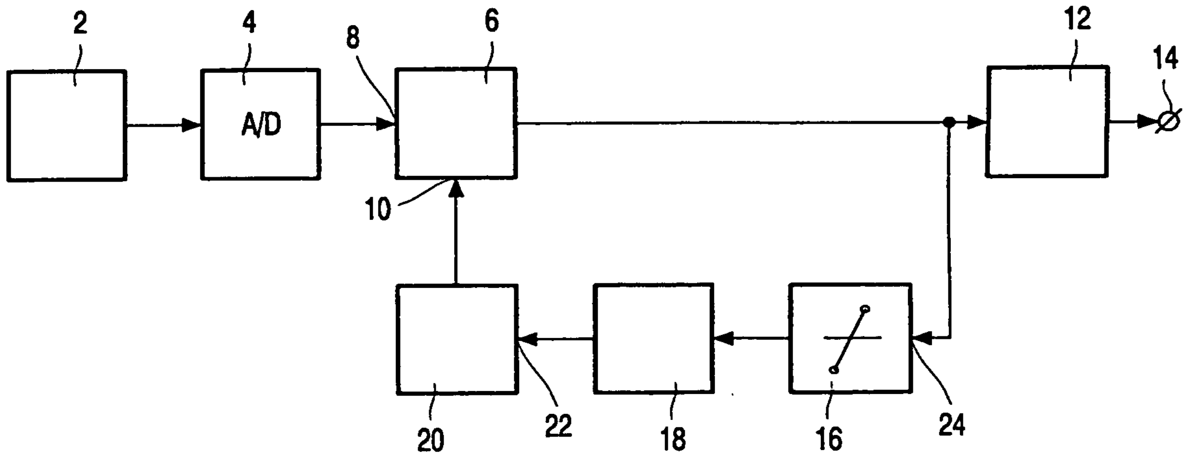


FIG. 1

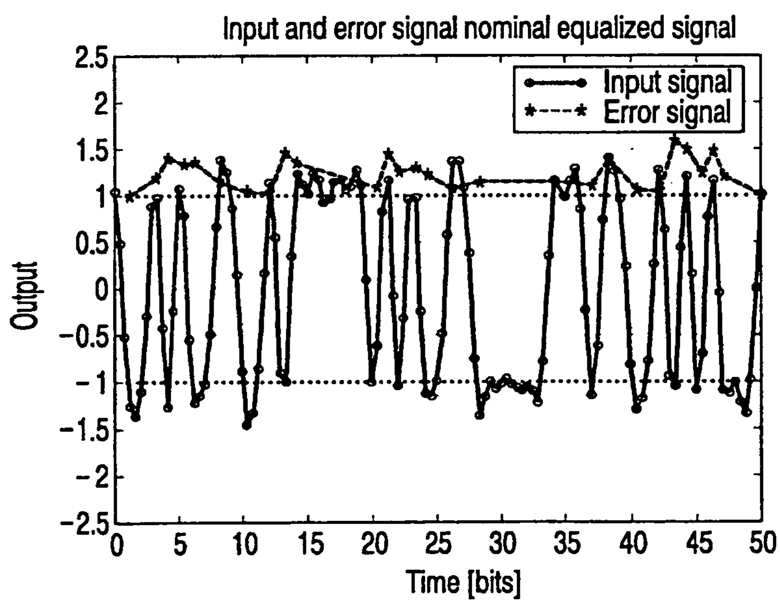
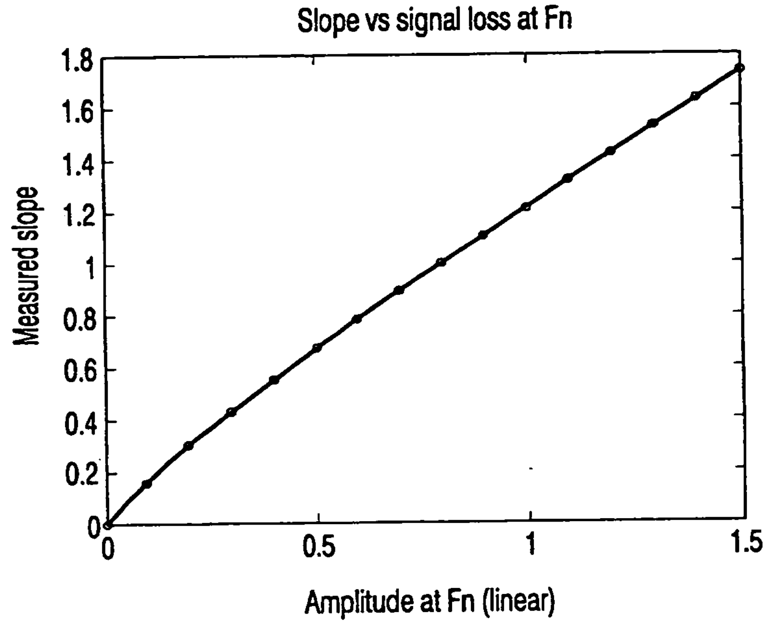
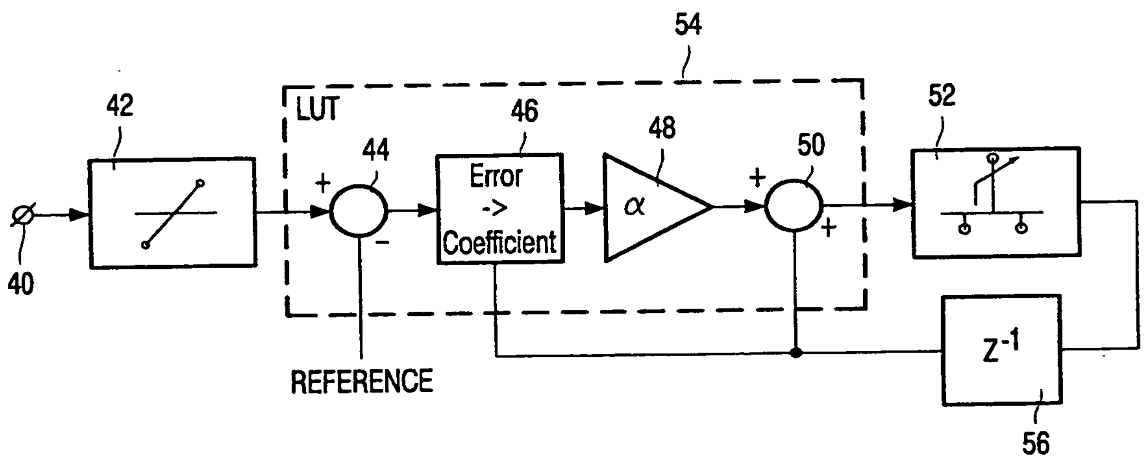


FIG. 2



Slope vs signal loss at Fn
Measured slope
Amplitude at Fn (linear)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0.5
1.5

FIG. 3



54
42
LUT
46
48
52
44
Error
->
Coefficient
α
50
40
REFERENCE
z-1
56

FIG. 4

3/3

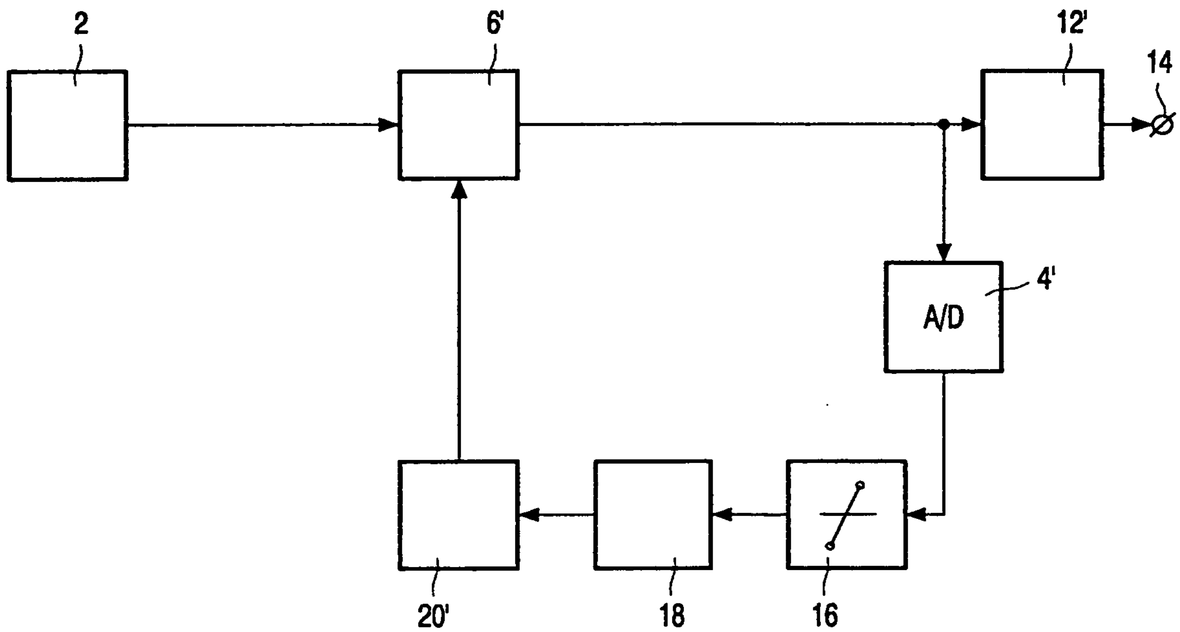


FIG. 5

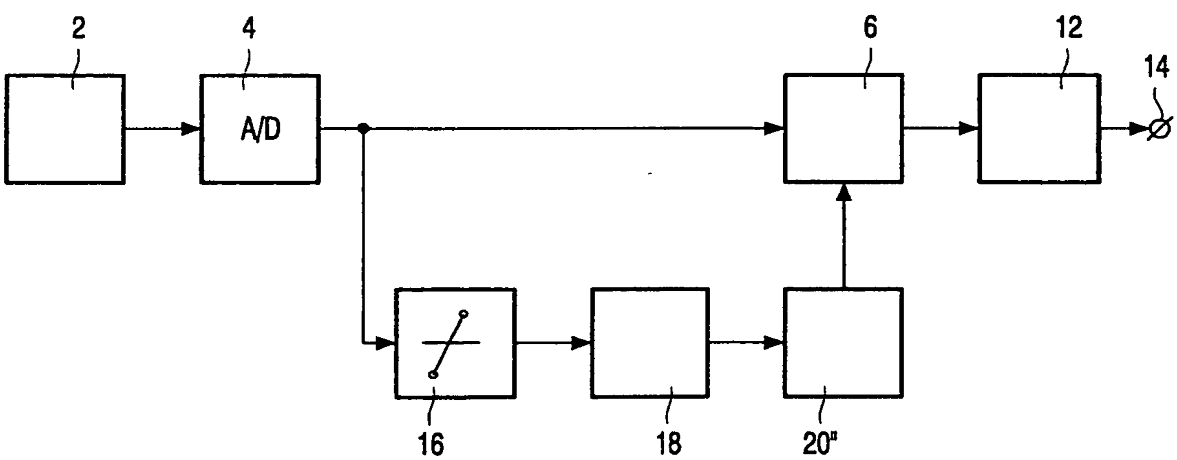


FIG. 6